Real-Time Measuring of Virtual Reality Impact on Biomarkers

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1. Introduction

By 2050, the number of people aged 80 years and above will more than triple, reaching 400 million individuals[1]. This might sound like good news to toast to with a glass of wine, but each sip from the glass leaves a bitter aftertaste. Starting in the fifth decade of life, humans are at an exponential risk of suffering from chronic conditions and disabilities as time passes[1]. Worldwide, the five biggest risk factors for death are high blood pressure, smoking, high blood glucose, air pollution and obesity in decreasing order[6]. In Finland, high blood glucose levels get the silver medal for being the second biggest risk factor for death[6]. But how do we avoid the hundreds of millions of elderly people seeing nothing but the walls of a hospital or nursing home in their last decades of life?

One of the leading researchers in the field of aging and genetics, David Sinclair, suggests that anyone, of any age or health status, should continuously monitor one's body to detect changes and irregularities early and prevent chronic disease[3]. Currently, we track our cars more than ourselves. Although Americans spend just under an hour in their car every day[5], the car's technical status is continuously tracked with its dashboard. By contrast, 40 percent of Americans skip at least one recommended medical test or treatment per year[4], leaving them with limited insights into their health.

According to Sinclair, the most important biomarkers that anyone should continuously track to identify and minimize signs of disease and aging are the following: glucose, heart function, inflammation, cortisol, lactate and blood oxygen[3].

In the context of this project work, we developed a personal gadget measuring some of the biomarkers mentioned by Prof. Sinclair to analyze the health status of an individual. The selected biomarkers indicate the current health status of a person, with respect to their healthspan, lifespan, biological and chronological age. Specifically, we track the following biomarkers non-invasively: glucose level, blood oxygen and heart rate. The device is not only aimed at individuals at risk or suffering from disease, but also at those who want to extend their mental and physical health to avoid these scenarios.

The longer an individual's biomarkers are tracked with the device, the more representative the gained data will be, as all biomarkers change throughout the day and are influenced by sleep, food intake, physical activity, stress and other factors. As the device is quite bulky and fragile at this first iteration, it would be neither handy nor safe enough to track users' values throughout an entire day. This is why we decided that our device will be coupled with a Virtual Reality (VR) application. The aim of using VR in combination with our physical device is to get the biggest range of values for each of the biomarkers that we possibly can in a short time window of a few minutes. Of course, this is not a perfect representation of an individual's fluctuations of these biomarkers during an entire day. For example, food intake has a significant impact on glucose levels and thus, the feeding status of an individual trying our device will have a high impact on his or her glucose levels. However, the VR scenes enable us to easily test the physical device on different people, to find out whether our approach is valid and accurate.

2. Technical implementation

Of all biomarkers that we choose to monitor with the device, blood glucose is the most challenging to track accurately without using invasive methods. Our approach is the following: Among all possible non-invasive methods that can generally be divided into optical methods, microwave methods, and electrochemical methods, our approach is based on optical spectroscopy. Knowing the material's behavior being exposed to light is dependent on its physical and chemical structure, it can be expected to use light as a magnifier to look for a certain substance in a compound. The absorption of light by human tissue is closely related to its wavelength[7]. By reflecting light on human tissue, ultraviolet light can be absorbed by proteins, infrared by water, and visible light by hemoglobin. Since these ranges do not pass the human tissue, it is difficult to obtain information from spectral data. However, Near-Infrared (680-2500nm) and Mid-Infrared (2500nm-25,000nm) are relatively suitable since they can pass through body fluids and soft tissues, are less prone to scatter and can be measured by both reflection and transmission. The reflection and transmission of light is dependent on the sample's thickness or density, which adds up to the challenge of measuring the blood glucose accurately. Knowing the human-body fluid is mostly made up of water, it should be taken into account that water absorbs a certain range of infrared light. Since water has two peaks between 1350 and 1520nm, and between 1790 and 2000nm, there remain small windows that are between 700-1100nm, 1500 and 1850nm, and 2000 and 2400nm that are suitable for measuring the blood glucose in the body fluid. However, knowing this information does not make the challenge any easier since the internal structure of the human body is quite complicated and complex. These internal structures vary depending on age, sex, skin color, and disease. Hence, we are required to make a multivariate model that can estimate the blood glucose level after acquiring enough relevant information to refine the model in order to get the highest accuracy.

Regarding the limitations stated above, in order to measure blood glucose, different solutions were taken into account. Knowing that blood glucose can be measured in the wavelength windows mentioned above, an infrared emitter LED was used in order to emit infrared light to the fingertips, and the reflection was measured using a phototransistor. In order to accurately measure different individuals' blood glucose with this technique, massive amounts of data are required that can be used to correlate physiological parameters, the reflection of light and the actual readings of blood glucose.

However, in order to create the model, we are required to design consistent hardware that maintains a stable condition during the measurement. For this purpose, high-quality and accurate components and sensors are required. As an example, the device shall be designed in a way that variations in the power supplier (voltage) or components temperature (conductivity) do not affect the accuracy or consistency of readings from the sensor.

Only measuring the infrared reflection from the fingertips cannot relate to blood glucose. The readings from the phototransistor vary in different conditions, and the values are not directly pointing out the blood glucose, even if the hardware has consistency, therefore, we used a special approach to measure the actual amount of blood glucose.

Using at least two different sources of light for measuring the intensity of light reflection from the fingertips helped us to find a relative value between all of the emitted lights, and the proportional value can be correlated to blood glucose.

In general, it seems the process is a straightforward solution. However, small differences may affect the results drastically. For example, sensors available to us had limitations that measuring any of the biomarkers except heart beat rate accurately turned out to be quite challenging. Available infrared emitters had a wavelength of 960nm, which limited us in our search for the most accurate infrared wavelength for measuring blood glucose. The same goes for the phototransistor used in this setup, which had a peak transmission near 900nm of infrared wavelength. Due to these limitations, our captured glucose measurements lacked precision. We managed to fine-tune the model so that it captures the blood glucose of our team members with high accuracy, but when other people try out the device, the glucose values have low accuracy. This fine-tuning was possible by using continuous and regular glucose meters as reference points to fine-tune our code.

For measuring the blood oxygen level, knowing that blood hemoglobin concentration is a determinant of oxygen delivery. As the red light reflection is higher when the blood oxygen level is higher, choosing the red light's wavelength requires to be precise. The commonly used red light's wavelength for measuring blood oxygen in medical gadgets and medical devices is 650nm. Therefore, the phototransistor that is being used for this purpose needs to match the emitter's specifications for better measurements. Since the components were not available, our device turned out to have the lowest accuracy when it comes to tracking blood oxygen.

Measuring heartbeat rate can be done using any kind of sensor that can pass light through the skin and be reflected in any amount. Even the slightest reflections can be amplified using electrical components that can relate to heart pulses, and the results compared to precise devices are identical. In the current setup, the heartbeat rate was measured using the infrared sensor and the phototransistor by the same approach stated above. The phototransistor measurements were amplified to a certain level to be measurable by the data acquisition device. Before recording the changes using an analog-to-digital converter, a resistor-capacitor low-pass filter with a 5Hz cutoff frequency was applied to the amplified signal in order to remove artifacts and unnecessary signals. Then, using peak detection algorithms, the peaks of the signal were identified, and an average of the peaks in a fixed-size window was calculated as the heartbeat.

All sensors related to capturing heart rate, blood glucose and blood oxygen were inserted into a 3D-printed finger cap that the users of our device can wear on one of their fingers. The dark environment inside the finger cap minimized noise data by limiting the effects of other light sources on the measurements of our device.

In the future, we would like to improve our physical device in the following domains: First of all, we need to find sensors that are better suited at our needs, which should lead us to reach better accuracy by default, especially for blood oxygen. Next, we would like to create a multivariate regression model with initial readings from different subjects, age, skin color, disease and reference blood glucose to improve the accuracy of our blood glucose readings when we test the device on subjects of different ages, genders or ethnicities.

Figure 1 shows the circuit schematic of our physical device, while Figure 2 shows the circuit in TinkerCAD and Figure 3 our end result.

3. Virtual Reality impact

Our physical device was paired with a self-developed VR application, which consists of three scenes. Each scene was developed to trigger different psychological and cognitive responses in the user to capture a range of values for each biomarker in a short time window. The first scene should provoke a calm and relaxed state of mind in the user. The moment the user puts on the headset, he will hear the gentle voices of an angelic choir. Strolling through a peaceful area with statues, Ancient columns, cherry blossom trees and a white Torri, a traditional element in Japanese gardens, the user will feel like walking in a heavenly place surrounded by soft clouds. Looking upwards, he will see different bird species flying peacefully from tree to tree. Colored spheres in the sky enhance the feeling of being in a heavenly place detached from Earth. In front of a lion statue, there is a red canvas with a button stand telling the user that a surprise will appear once he presses the button. The seducing surprise turns out to be a brutal teleportation from the bright and angelic scene into a dark and horrific place. Standing in the center of a graveyard, the user will hear the grunts of zombies approaching him from all sides, while his eyes will search for an escape. He will quickly realize the only way to avoid getting killed by the zombies is to grab one of the swords laying on the ground in front of him and stabbing them. But the first zombie bodies falling down in front of the user won't give him any hope for a fast escape, as he realizes the herd of zombies seems to grow infinitely. At some point, the user will be attacked from every side, leading to his virtual death. Experiencing this zombie scene should evoke bodily responses similar to a stressful situation in real life, leading to changing values in some of the biomarkers. The user sees a blood-red screen in front of his eyes, while he is teleported into the third scene. Being welcomed with the melody of a popular Christmas song and snow falling from the sky, the user's eyes stroll through the festive miniature golf place. Between snowmen and reindeer, he grabs a miniature tennis racket and fires one ball after the other toward the hole. This task turns out to be difficult, as the racket needs to hit the ball from the correct angle and with sufficient force. While the first scene has limited interactions to ensure a maximally calming experience, the interactivity in the horror scene leads enhances the feeling of stress and enables to capture the user's concentration playing miniature golf.

This VR experience was run on a Meta Quest 2, owned by one of our team members. The video linked below shows all three VR scenes in a live user demonstration.

4. Usage

All three members of our group tested the physical device in combination with the VR scene and all of us experienced some inconveniences from the current setup. To display the values of each biomarker, the physical device has to be connected to a computer during the measurement session. As our VR experience requires a lot of movement and includes many interactions, users must be careful not to move away further from the computer than the length of the cable between the computer and the device allows. Another problem is the attachment of the device to the arm of the user. As the circuit of our device needs quite a lot of wires, it is quite vulnerable. This is why we decided to put the device inside a thin scarf that is wrapped around the user's wrist. This scarf allows for enough room to ensure the wires or other parts of the circuit aren't damaged during the VR experience. By contrast, all of our team members reported that wearing the 3D-printed finger cap during the VR session wasn't creating inconveniences during any of the interactions. In the future, we will improve our setup, by either using soldering equipment to drastically reduce the size of our device or by inserting all components into the finger cap, for example by using a small, rounded battery.

5. Project Codebase

The code for the physical device was written in C++ and Python and can be found in this GitHub repository: https://github.com/abolfazljalali/GMeter. The code for making the VR scene was written in C Sharp, as it was created in Unity. The code for the VR Scene can be found in this repository: https://github.com/superintelligence-lab/healthring.

6. Project Video

A video of a user engaging in our VR Experience while being attached to our physical device is uploaded on YouTube: https://youtu.be/HSj71tfiaZw. The video is split into three scenes. One shows the user in the VR Scene, one displays the real-time values of his heart rate, blood oxygen and blood glucose as captured from our device and the last one displays the user's current view in the VR scene.

References

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7. Appendix

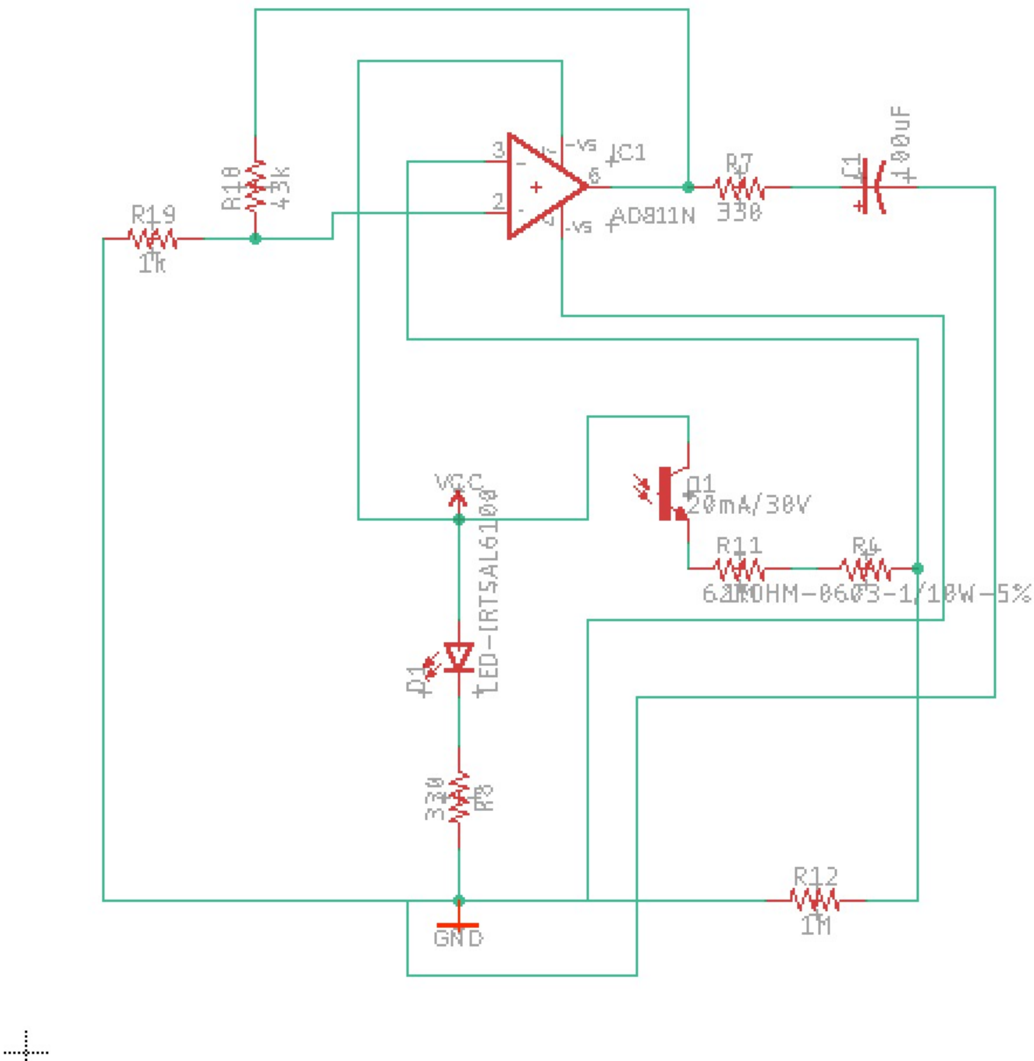

Figure 1. Circuit schematic of our physical device.

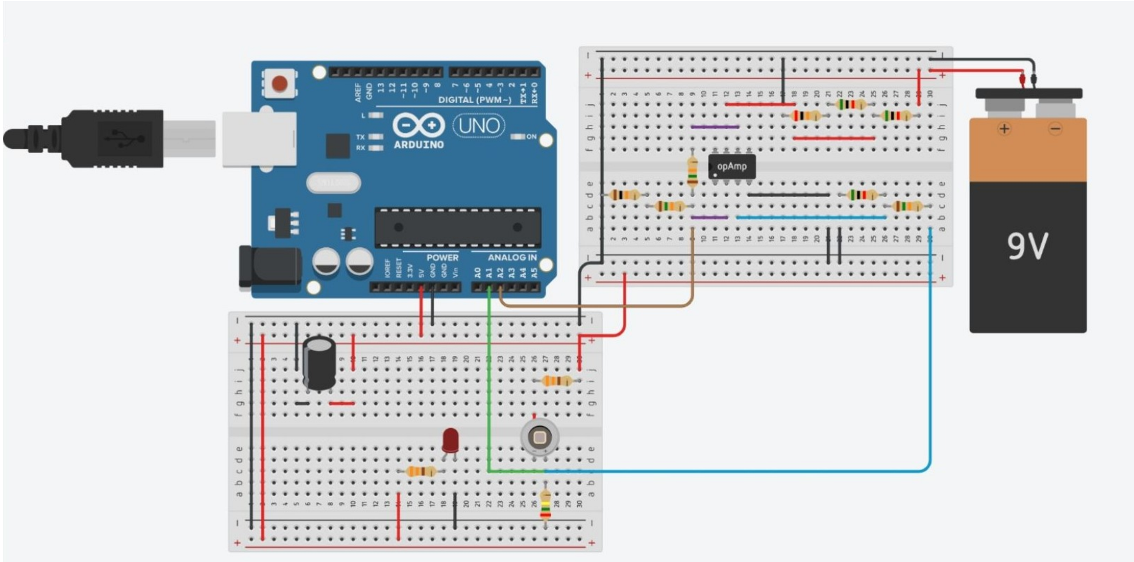

Figure 2. Circuit of our device in TinkerCAD.

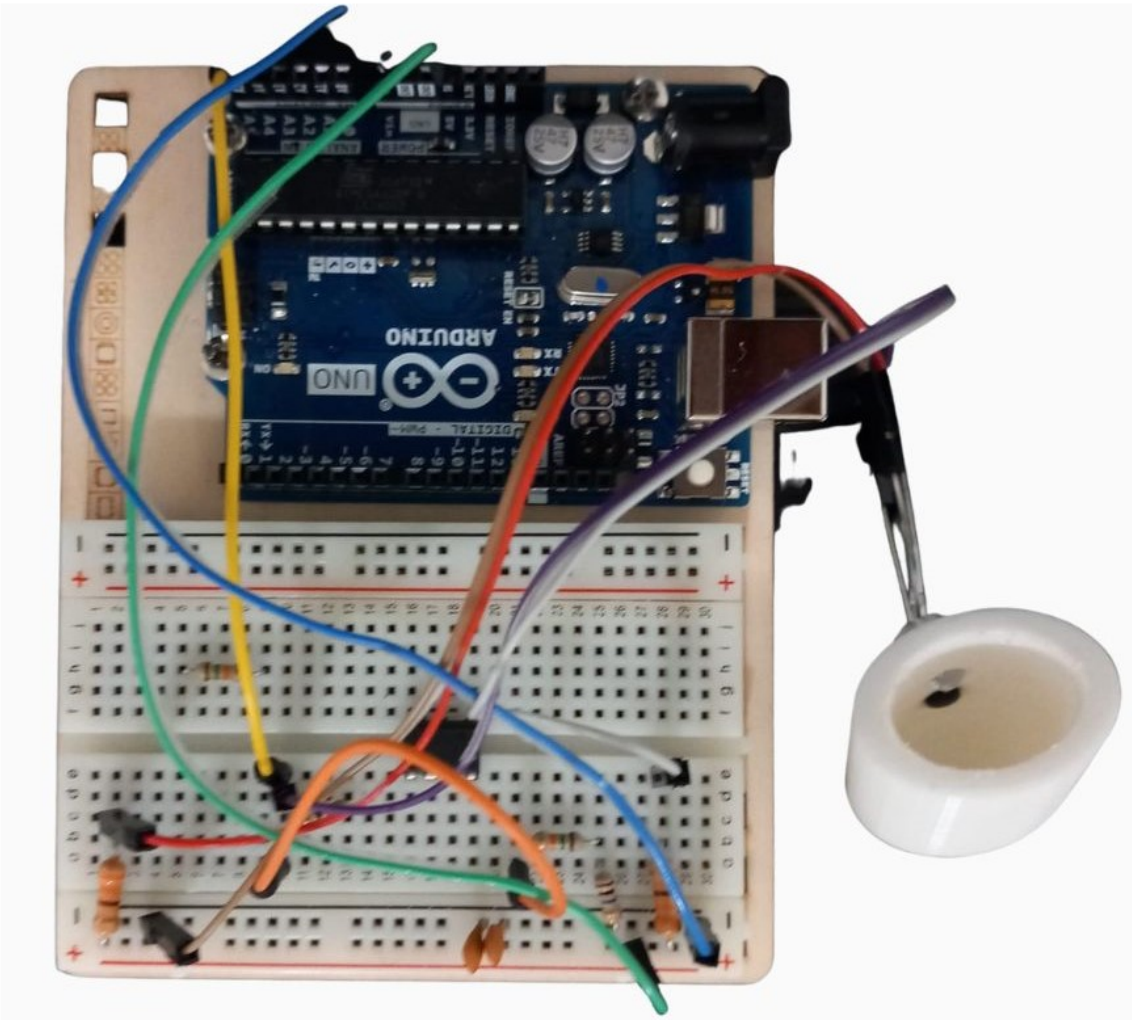

Figure 3. Physical circuit used to measure the three biomarkers.